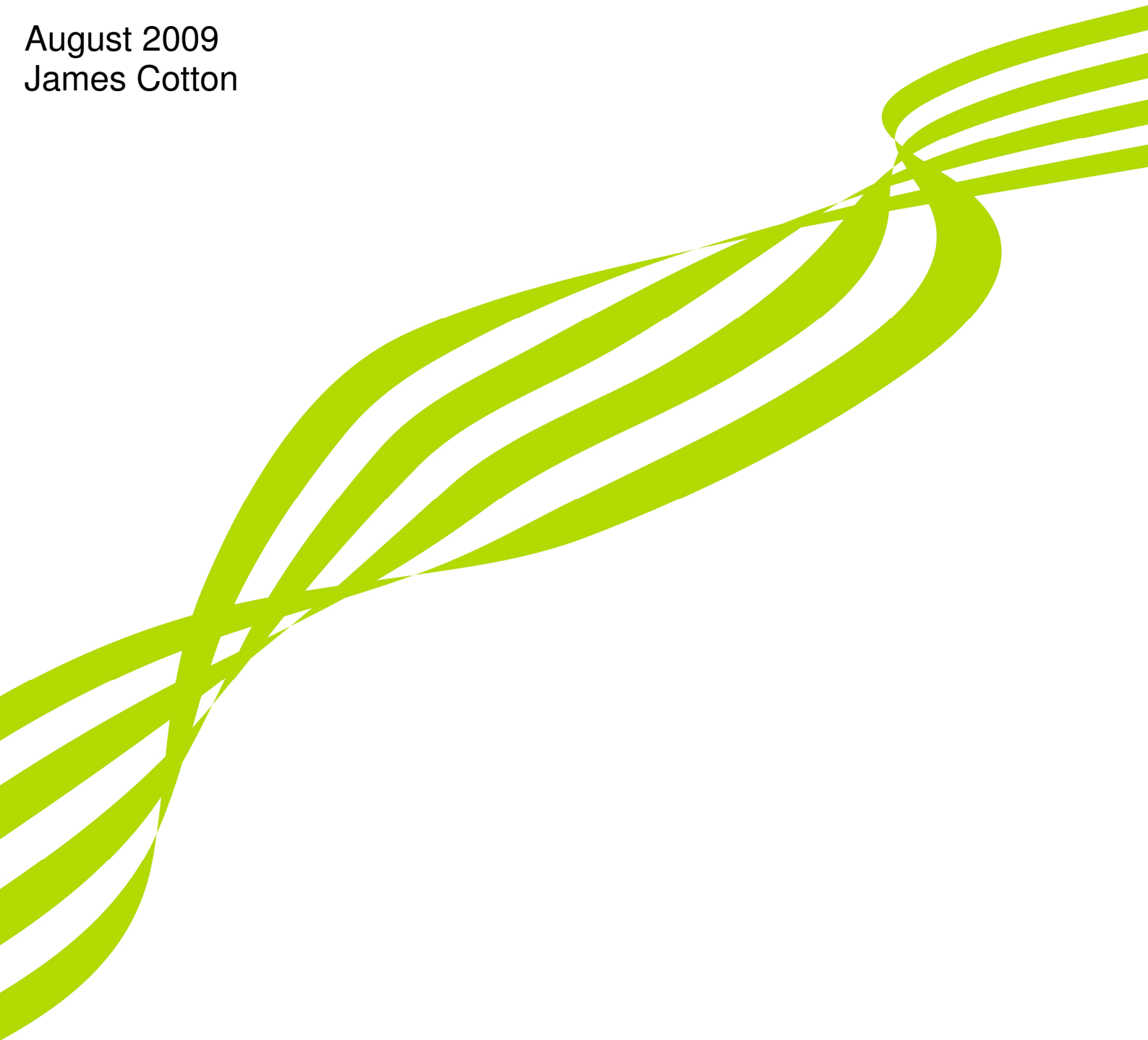
A comparison of QuikSCAT with buoy, ship and radar altimeter wind speeds and evaluating the need for a new bias correction
Technical Report No. 538

August 2009

James Cotton



Document review history

Author: J.A. Cotton

Date	Version	Action/comments	
06/04/2009	0.1	First draft for consideration by Dave Offiler	
13/05/2009	0.2	Draft revised following comments made to 0.1	
21/05/2009	0.3	Draft 0.2 revised following discussion with Simon Keogh	
02/06/2009	0.4	Added inputs from ocean and wave teams to 0.3	
23/06/2009	0.5	Version 0.4 reviewed by Dave Offiler –no changes required. Added contents page and abstract.	
04/08/2009	1.0	Amended following comments by John Eyre.	

Approvals

This document requires the following approval:

Name	Title	Version	Date
John Eyre	Head Satellite Applications	1.0	04/08/2009

Circulation

This document should be circulated to the following:

Name	Title	Date of issue	Version
James Cotton	Satellite Wind Scientist		1.0
Dave Offiler	Head SASG		1.0
John Eyre	Head Satellite Applications		1.0

Contents

Section	Title	Page
	Abstract	3
1	Introduction	4
2	Comparison of QuikSCAT with radar altimeter winds	5
	2.1 – Method	5
	2.2 - QuikSCAT and ERS radar altimeter statistics	6
3	Comparison of QuikSCAT with moored buoys	9
	3.1 – Method	9
	3.2 - QuikSCAT and buoys statistics	11
4	Comparison of QuikSCAT with SHIP reports	14
	4.1 – Method	14
	4.2 - QuikSCAT and SHIP statistics	16
5	New QuikSCAT bias correction	21
	5.1 – Method	21
	5.2 - New polynomial fit	22
6	NESDIS Seawinds test data	27
7	Conclusions and recommendations	28
8	References	30
9	Acknowledgements	30

Abstract

This report compares ocean surface wind speeds from QuikSCAT with wind data from the radar altimeter on board ERS-2, tropical moored buoys, fixed platforms, ships and buoys reporting to the Met Office in SHIP code format. It is shown that in most cases it is the uncorrected, rather than the bias-corrected, QuikSCAT wind speeds which agree better with the other ocean wind observations. It is also shown that the model background is weaker by between 4% and 17% compared to the observations discussed in this report. As a result of these findings a new set of simpler linear bias correction coefficients are proposed for QuikSCAT. These are shown to provide the best fit to the data when binned by model background and observation speed. The new coefficients are shown to reduce the mean O-B (observation – model background) bias to -0.01m/s compared to the current bias of -0.27 m/s and a recommendation is made that these new coefficients should be included in the next operational change with sufficient notice supplied to the ocean/wave teams.

1. Introduction

The aim of this report is to investigate the QuikSCAT (NASA's Quick Scatterometer) bias correction to see if it is still providing a positive benefit to NWP through comparison with other wind data products. The principle motivation for this study is the lesson learnt from FRTR 472 (Keogh & Offiler, 2005) that bias corrections can drift and periodic revisits to the formulation or coefficients is necessary.

A bias correction is currently applied to QuikSCAT wind speeds prior to their assimilation in the Met Office model. This is done through a speed-dependent polynomial correction in the Met Office Observation Processing System (OPS) of the form:

$$y = c_0 + c_1 x + c_2 x^2 + c_3 x^3, \quad c_i \in R$$

where $x =$ observed QuikSCAT wind speed and $y =$ bias-corrected wind speed. The impact of the current bias correction which has been operational since June 2005 can be seen in Figure 1.1 which has been taken from daily QuikSCAT monitoring. This shows that when no bias correction is applied QuikSCAT is biased fast relative to background wind speeds by approximately +0.5m/s (or equivalently, QuikSCAT is 8% stronger than the model). The effect of the current bias correction is to reduce this bias such that QuikSCAT is in fact biased low compared to the model background with an observed-background (O-B) value of roughly -0.3m/s. However this has not always been the case as long term monitoring plots indicate a typical O-B value after correction of -0.15m/s at the beginning of 2006. This is likely due to improvements in the model in the intervening years which have also resulted in a 10% fall in O-B RMS error over the same period.

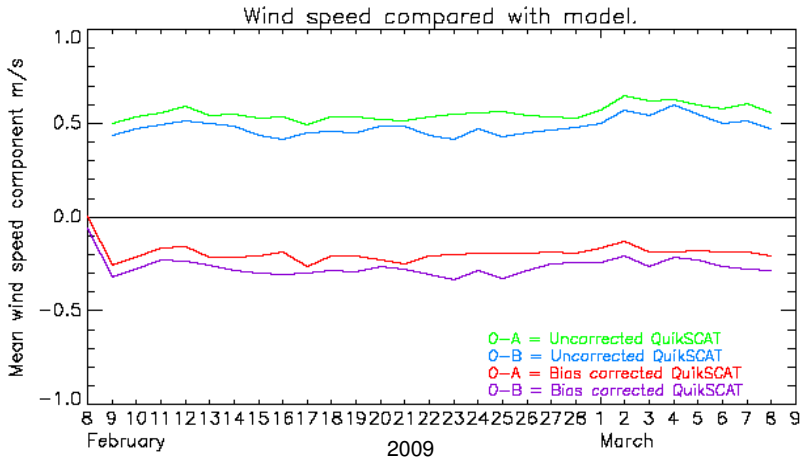


Figure 1.1 Time series of observed-analysis (O-A) and observed-background (O-B) values from routine QuikSCAT monitoring.

To investigate the performance of the current operational coefficients the uncorrected and corrected QuikSCAT winds, together with model field values, are compared to other sources of wind data over the world's oceans. In section 2 of this report a comparison is performed with wind speed data obtained via the radar altimeter on board the ERS-2 satellite. Section 3 presents a comparison of QuikSCAT with moored buoys reporting in BUOY code which are principally located in the deep water tropical arrays. To validate these findings one further comparison is made in section 4 with data reported in SHIP code which includes reports from ships, light vessels, buoys, rigs and fixed ocean platforms. In section 5 a new set of bias correction coefficients are proposed for inclusion in the scatterometer namelist using two months of QuikSCAT and model data.

2. Comparison of QuikSCAT with radar altimeter winds

In this section QuikSCAT wind speeds are compared to independent radar altimeter observations from the ERS-2 satellite. This updates the work done previously between the two instruments by Keogh and Offiler (2005) and allows the findings to be compared.

The polar orbiting ERS-2 satellite was launched in April 1995 and its payload is entirely devoted to remote sensing. Alongside its wind scatterometer instrument it also carries a microwave Ku-band (13.8 GHz) radar altimeter which is a nadir pointing sensor designed to measure the time return echoes from ocean and ice surfaces. The URA product used in this study provides information on significant wave height and surface wind speed.

The main limitation of the altimeter data is the data coverage provided by ERS-2 since the permanent failure of the on board tape recorder in June 2003. As a result, data is acquired in real time whenever the satellite is within visible range of a ground station. This limits data coverage to the areas given in Table 2.0.1 but represents an improved situation since the last comparison performed in July 2004, with the Indian Ocean data only available since October 2006. The radar altimeter winds speeds are not assimilated at the Met Office but do provide a useful independent source of observations to enable a bias comparison with QuikSCAT scatterometer data.

• North Atlantic	• Mediterranean	• Gulf of Mexico
• small area of Pacific west of the US, Canada and Central America	• small area near South Africa (missing during the period of study)	• Chinese Sea
• small area of the Indian Ocean south east of Thailand and Indonesia	• Southern Ocean near to the Antarctic	• Southern Ocean south of Australia and New Zealand

Table 2.0.1 Global coverage of the ERS-2 satellite.

2.1 Method

ERS Radar altimeter data (ESAURA) was extracted daily from the Met Office Meteorological Database (MetDB) for a period of 32 days from 1st February to 4th March 2009 producing on average 21,500 useful wind speed observations each day. These were collocated with approximately 1.5 million QuikSCAT observations extracted each day from MetDB over the same period, along with the model mergeback data. Each altimeter wind speed occurring at time *t* was matched temporally and spatially to any scatterometer observations falling within a 60 minute time window [*t*–30 mins, *t*+30 mins] and within a 25km radius of the altimeter observation. If more than one QuikSCAT observation was a match then an average value was taken for comparison. A final quality control was then performed which included a background check to remove any poor quality matchups, as well as removal of any suspicious individual altimeter observations for which the wave height standard deviations were missing.

The matchup process yielded 2372 collocations for the period of study and the global distribution of these matchups are shown in Figure 2.1.1. Compare this with Figure 3.1.1 of FRTR 472 (matchups near the Arctic only) to see the improved data coverage this time round which should help offset any seasonal variations. The collocations are confined to two regions located between 60° and 80° N/S. In the Northern Hemisphere these matches encompass areas of the Greenland, Norwegian and Barents Sea. In the Southern Hemisphere the matches occur only in the extreme Southern Ocean. The fact that the collocations between the two satellites only occur at high

latitudes is to be expected as these areas are imaged more frequently than tropical latitudes, resulting in a greater chance of the satellite swaths overlapping within the required time window.

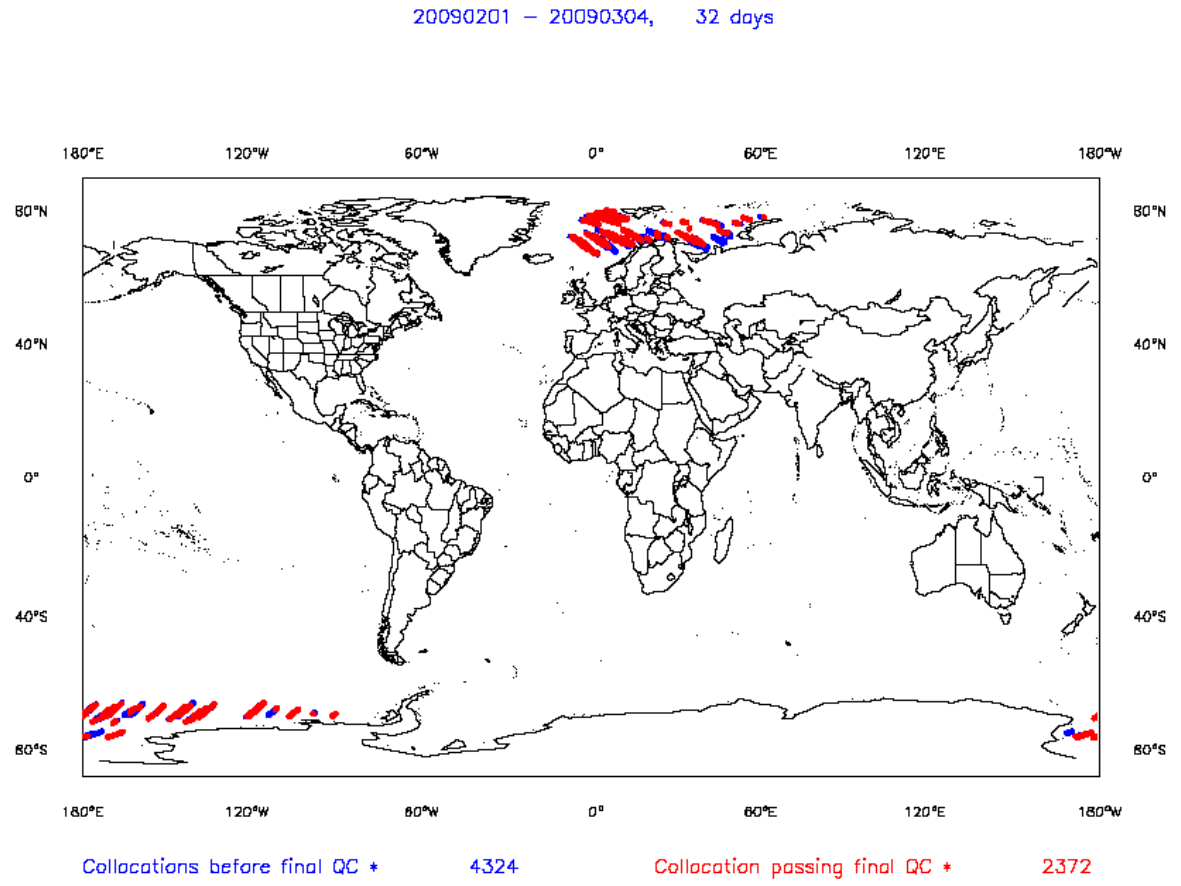


Figure 2.1.1 Coverage of QuikSCAT and altimeter collocation points.

2.2 QuikSCAT and ERS radar altimeter statistics

The method outlined in section 2.1 yielded 2372 collocations for the period, with an average distance and time difference of 16.7km and 16 mins 20s respectively between observations. The distribution of ERS radar altimeter (ERSURA) wind speeds used in the collocations is shown in Figure 2.2.1. This shows that most altimeter winds were less than 15m/s and only a handful exceeded 20m/s. The mean altimeter wind speed for collocations in this period was in excess of 8m/s - more than double the average found in FRTR 472.

A summary of the key statistics is presented in Table 2.2. An important first point to note are the QuikSCAT minus model background (O-B) wind speed values for the collocations. These indicate that uncorrected QuikSCAT winds have a bias of approximately +0.5m/s, whilst the bias-corrected winds have a bias of approximately -0.3m/s against the background. The O-B values (as well as the analysis values) are almost identical to those typically found via daily monitoring of QuikSCAT (see introduction) which implies the results found through these matchups are a good representation of the current bias situation

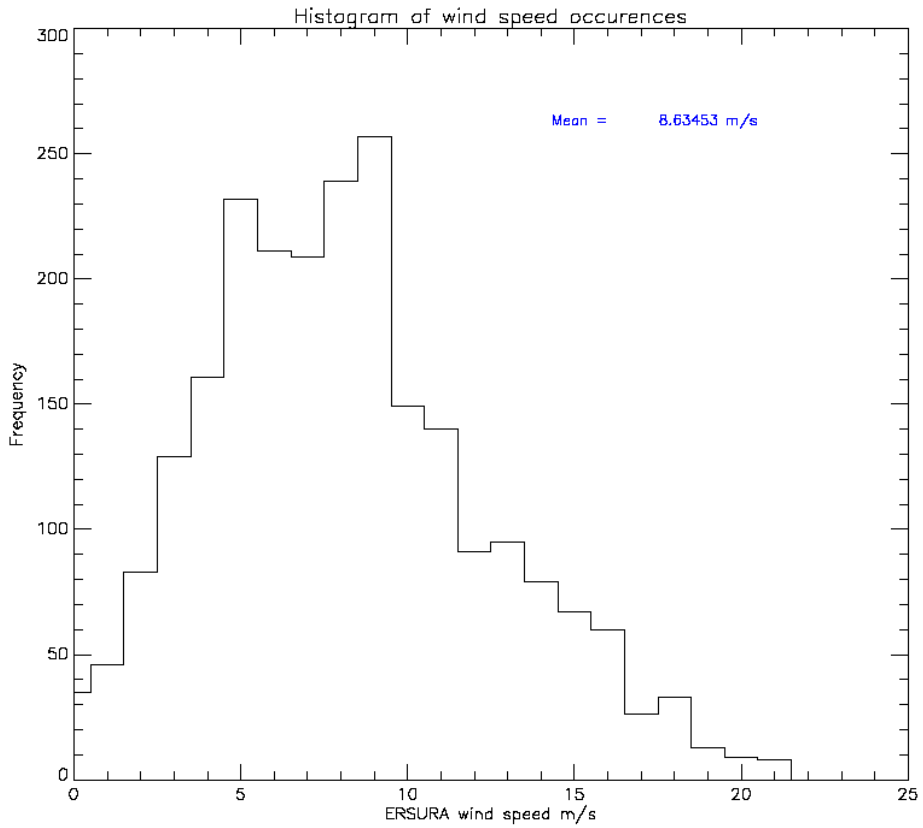


Figure 2.2.1 Distribution of collocated ERSURA wind speeds.

Component	Std Dev m/s	Mean m/s	RMS m/s
QS - ERSURA	1.184	0.158	1.194
BCQS - ERSURA	1.241	-0.640	1.396
ERSURA - Bg	1.095	0.342	1.147
ERSURA - A	1.381	0.412	1.441
QS - A	1.249	0.570	1.372
BCQS - A	1.214	-0.227	1.235
QS - Bg	1.085	0.500	1.194
BCQS - Bg	1.075	-0.297	1.115

Key:

- QS = uncorrected QuikSCAT
- BCQS= bias-corrected QuikSCAT
- Bg = model background wind speed
- A = model analysis wind speed

Table 2.2 Summary of results for ERSURA – QuikSCAT collocations.

It is apparent from the results that ERS radar altimeter winds agree better with the uncorrected QuikSCAT wind speeds - with QuikSCAT exhibiting a small fast bias of +0.16 m/s (Figure 2.2.2). The bias-corrected QuikSCAT winds show a much larger negative bias of -0.64 m/s compared to the altimeter winds which may indicate that the current coefficients are overcompensating somewhat, but further evidence will be needed to corroborate this. The altimeter wind speeds are biased fast compared to the background (+0.34m/s) corresponding to the background being roughly 4% too weak. A schematic representation of the biases with respect to the altimeter wind speeds is given in Figure 2.2.3.

The results found here are quite different from the results of FRTR 472 which showed that QuikSCAT was biased much faster compared to ERSURA (+1.0 m/s), probably in large part due to the shorter study period involved which resulted in only 961 matchups.

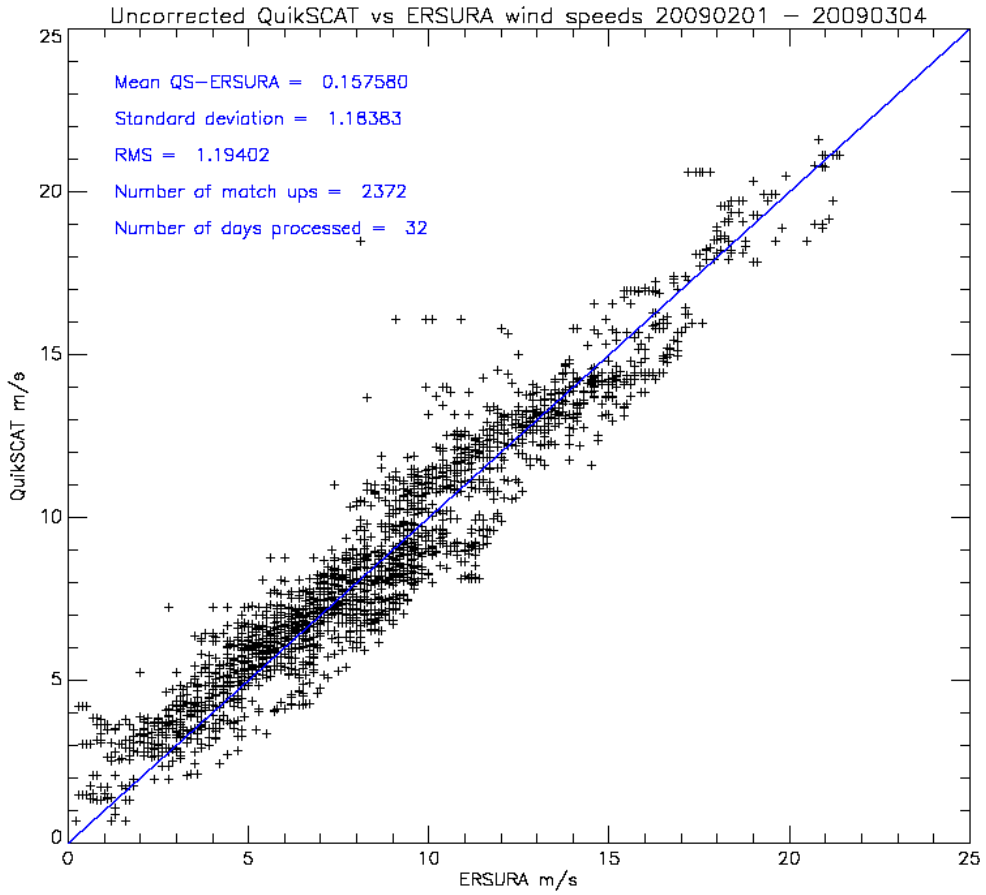


Figure 2.2.2 ERSURA altimeter wind speed observations plotted versus uncorrected QuikSCAT wind speeds. The line y=x is plotted in blue for ease of comparison.

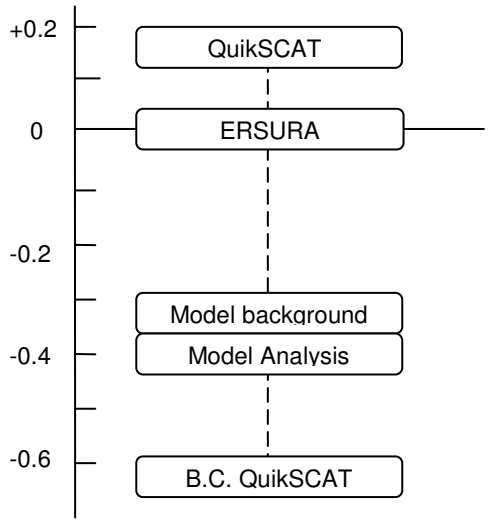


Figure 2.2.3 Schematic showing the biases with respect to ERS radar altimeter wind speeds. Note that here 'QuikSCAT' refers to the uncorrected winds.

3. Comparison of QuikSCAT with moored buoys

In this section QuikSCAT wind speeds are compared to in-situ moored buoy data to look for any bias in the scatterometer data. Moored buoy data was not used in the comparisons of FRTR 472.

The data under consideration here has been transmitted in the BUOY code format of the World Meteorological Organisation (WMO). Each ocean platform reporting on the Global Telecommunication System (GTS) is allocated an identification, or WMO number, dependent upon its location and platform type. Here we are interested only in data obtained from moored buoys and not drifters as a recent report (Ingleby, 2009) found that, whilst moored buoys generally provide good quality winds, drifter winds are of rather poor quality (not assimilated at the Met Office). The majority of moored buoys are located in the deep water tropical TAO, TRITON, PIRATA and RAMA arrays. The TAO/TRITON array is located in the Pacific and is a major component of the El Niño/Southern Oscillation (ENSO) Observing System (Figure 3.0.1). The PIRATA array is located in the Atlantic aiding the monitoring of hurricane activity, whilst the RAMA array in the Indian Ocean focuses on seasonal variability and monsoon activity.

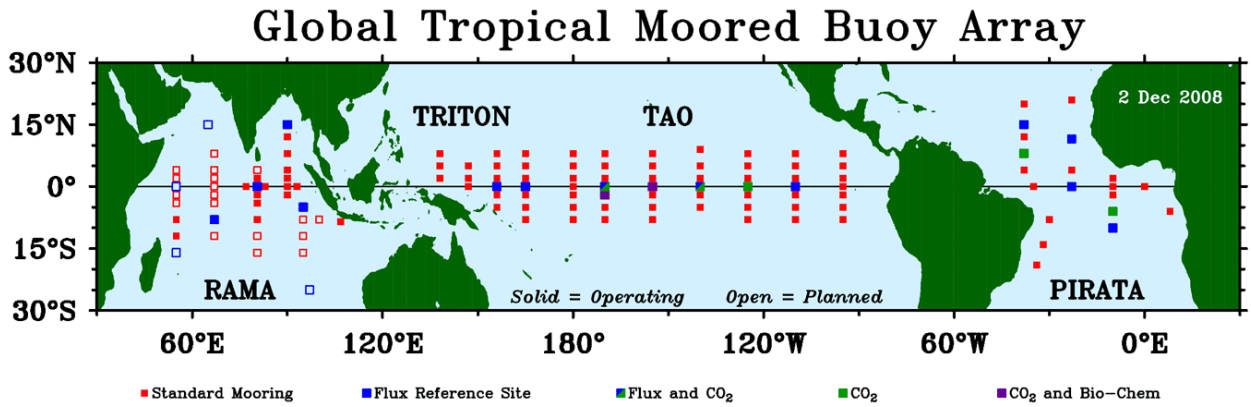


Figure 3.0.1 Map of deep water tropical moored buoy arrays (image from NOAA).

One caveat of buoys is that they may underestimate very strong winds due to buoy motion and wave sheltering effects (Gilhousen, 2006). There is some evidence that when the significant wave height exceeds 4-5 m, the anemometer height of most buoys, sheltering and tilting reduces the measured wind speed. It was found that during Hurricane Katrina a moored buoy (5m anemometer height) was consistently tilted by 20° or more from vertical (Howden et al, 2008). As a result the traditional vane and propeller anemometer significantly underestimated winds in excess of 15 m/s compared to a sonic anemometer which was able to correct for buoy pitch and roll.

3.1 Method

The period of analysis was from 1st January to 28th February 2009 (59 days). Data in BUOY code for January and February was read in from Bruce Ingleby's archive located at '/data/local/frbi/marine/frommetdb/Global'. This data was then processed to select only moored buoys which are discernible via their WMO identifiers. Buoy WMO's are a five digit number of the form *abnnn,* where *a* is the WMO region, *b* the sub-area and *nnn* the serial code with 000-499 corresponding to moored buoys. Moored buoys have an approximate anemometer height of 4m. Therefore the wind speeds were adjusted using the logprofile (Equation 1) from KNMI's TurboWin logbook software (Benschop, 1996). The correction from an observed wind speed U to a wind speed valid at 10m U_{10} was necessary to enable the comparison with scatterometer data. Stability dependence was not considered in the adjustments to 10m (atmospheric stability is estimated using air and sea temperatures). However the greatest change usually comes in the adjustment

from U to U_{10}, whilst the difference between $U_{10}$and U_{10}neutral is much smaller (Thomas et al, 2005). In practice, most of the world's oceans are near-neutral stability so this is a valid assumption for these buoys.

$$\frac{U(z)}{U(10)} = \frac{\ln\left(\frac{z}{0.0016}\right)}{8.7403} \qquad (1)$$

z : observation height above mean sea level (m)
$U(z)$: average observation wind speed at height z
$U(10)$: average 10m wind speed

The same collocation procedure was used as outlined in section 2.1 i.e. QuikSCAT observation occurring within +/- 30 minutes and 25km of a moored buoy observation. A final quality check removed any duplicate observations and any erroneous matchups with an extreme wind speed bias (none were found in this case).

The matchup process yielded a total of 1610 collocations and their global distribution can be seen in Figure 3.1.1. By comparing this to Figure 3.0.1 it can clearly be seen that the majority of coverage is provided by the deep water tropical moored buoy arrays in the Atlantic, Pacific and Indian Oceans.

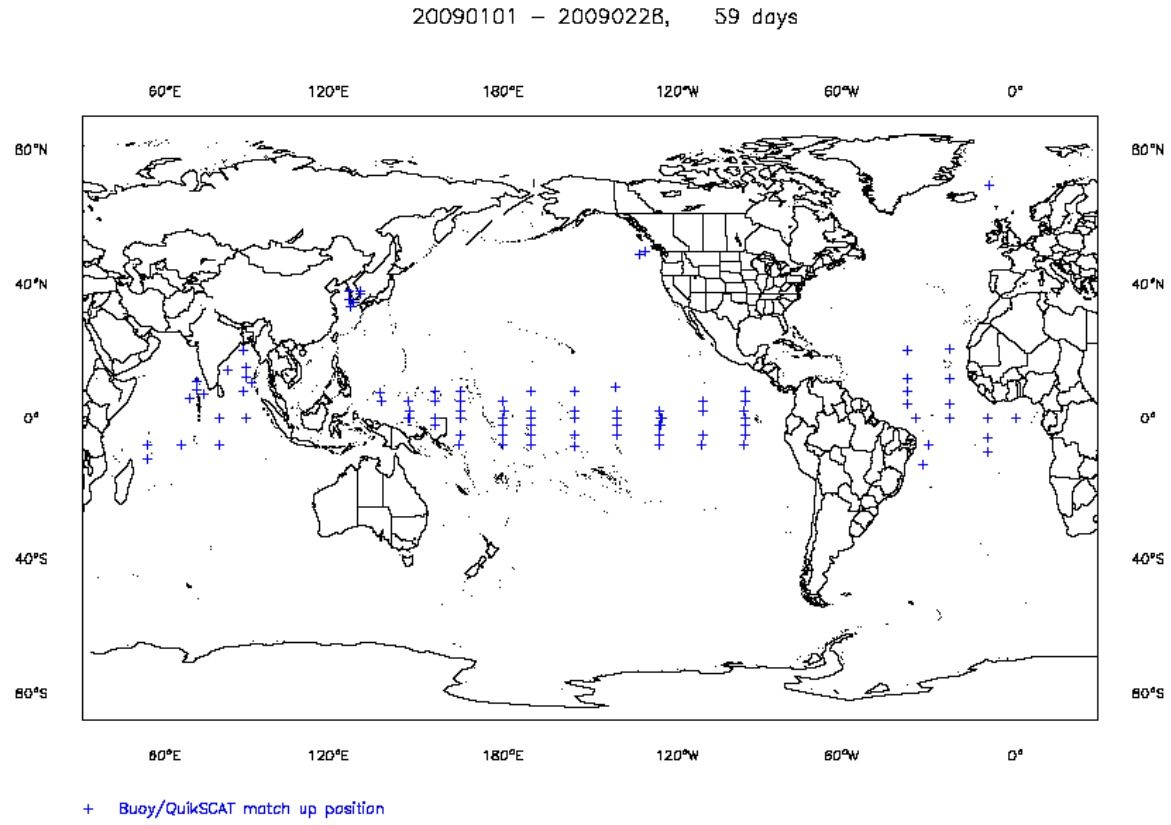


Figure 3.1.1 Global coverage of QuikSCAT and moored buoy collocation points.

3.2 QuikSCAT and buoy statistics

The mean matchup distance for the 1610 QuikSCAT and buoy collocations was 16.6km with a mean absolute time difference of just over 14 minutes, both slightly better than the equivalent altimeter values. The mean collocated buoy wind speed was slightly slower at 6.8 m/s and this time there were virtually no winds exceeding 15 m/s. A summary of the main statistics for the QuikSCAT and buoy comparison is shown in Table 3.2.

Component	Std Dev m/s	Mean m/s	RMS m/s
QS-buoy	1.134	0.005	1.134
BCQS-buoy	1.195	-0.661	1.366
buoy-Bg	1.477	0.743	1.653
buoy-A	1.235	0.839	1.492
QS-A	1.086	0.844	1.375
BCQS-A	1.040	0.177	1.054
QS-Bg	1.299	0.748	1.499
BCQS-Bg	1.223	0.082	1.225

Key:

- QS = uncorrected QuikSCAT
- BCQS= bias-corrected QuikSCAT
- Bg = model background wind speed
- A = model analysis wind speed

Table 3.2 Summary of results for QuikSCAT-buoy collocations.

The results show a very strong agreement between the buoy wind speeds and the uncorrected QuikSCAT wind speeds, with a near zero mean bias as shown in Figure 3.2.1. Such a close agreement can be partly explained by the fact that the geophysical model function (GMF) used to derive the wind speed and direction from the backscattered power, is tuned in part with buoy observations (Hoffman and Leidner, 2005). There is a much larger bias when the buoys are compared to the bias-corrected QuikSCAT winds, which exhibit a slow bias of 0.66 m/s in comparison to the buoys (Figure 3.2.2). A schematic representation of the biases with respect to the buoy wind speeds is given in Figure 3.2.3 for ease of comparison. Comparing the plots in Figures 3.2.1 and 3.2.2 it appears that the current bias correction coefficients are over-correcting the QuikSCAT winds to some extent and this is particularly apparent in the range 5-12 m/s. This is confirmed by the histogram plots in Figure 3.2.4a which show the QuikSCAT-buoy bias binned by buoy wind speed for both corrected/uncorrected cases. Figures 3.2.4a/b show that both the uncorrected and bias-corrected QuikSCAT winds have a significant positive bias (up to 2m/s) compared to the buoy and background for very low buoy measured wind speeds.

The buoys are biased fast by 0.74m/s when compared to the model background with a ratio of 1.17 between the two. This ratio is slightly larger than that found in Ingleby's report which suggested the background was 10 % too weak. When the satellite data is compared to the model background for the matchups the statistics are slightly different from what we would normally expect. For instance, we know from routine daily monitoring that the normal O-B bias is approximately -0.3m/s, whereas here the bias is +0.08. This discrepancy may be down to the lower number of buoy collocations for the period (1610) in comparison to the millions of QuikSCAT observations received daily. Another factor is that the buoy's coverage is limited to the tropics with a wind speed range which is going to be biased low with respect to the global mean (clearly some speed-dependence in these relative biases). However the key point to take from this comparison is that, as was the case for the altimeter winds, the bias-corrected QuikSCAT winds appear to be performing worse than the uncorrected winds.

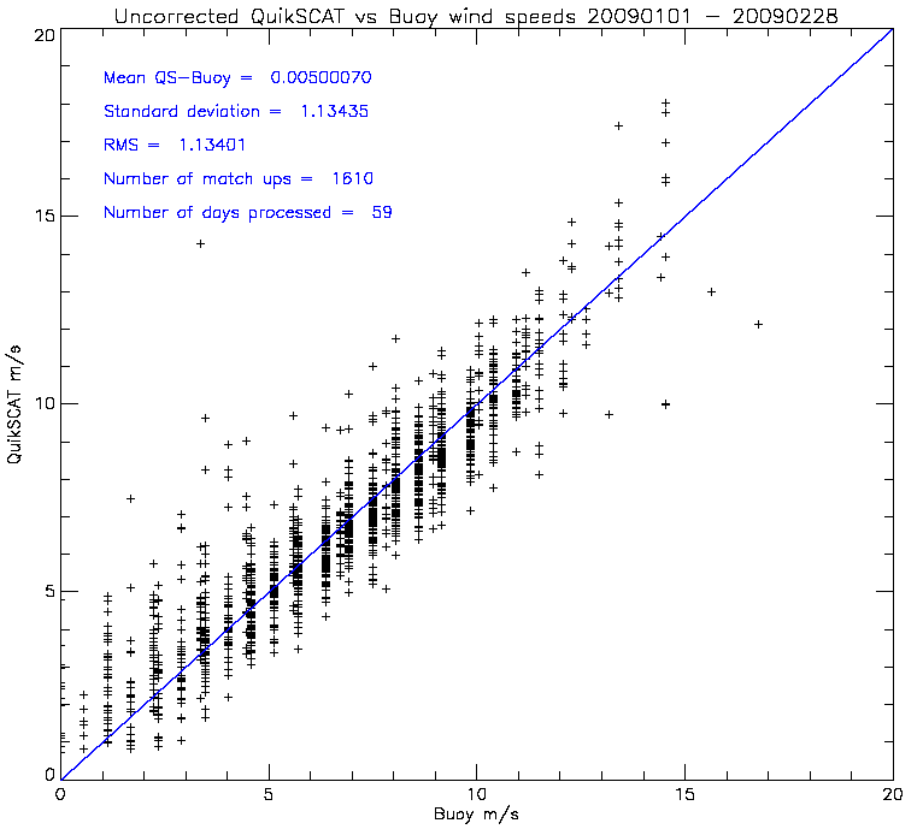


Figure 3.2.1 Moored buoy wind speed observations plotted versus uncorrected QuikSCAT wind speeds.

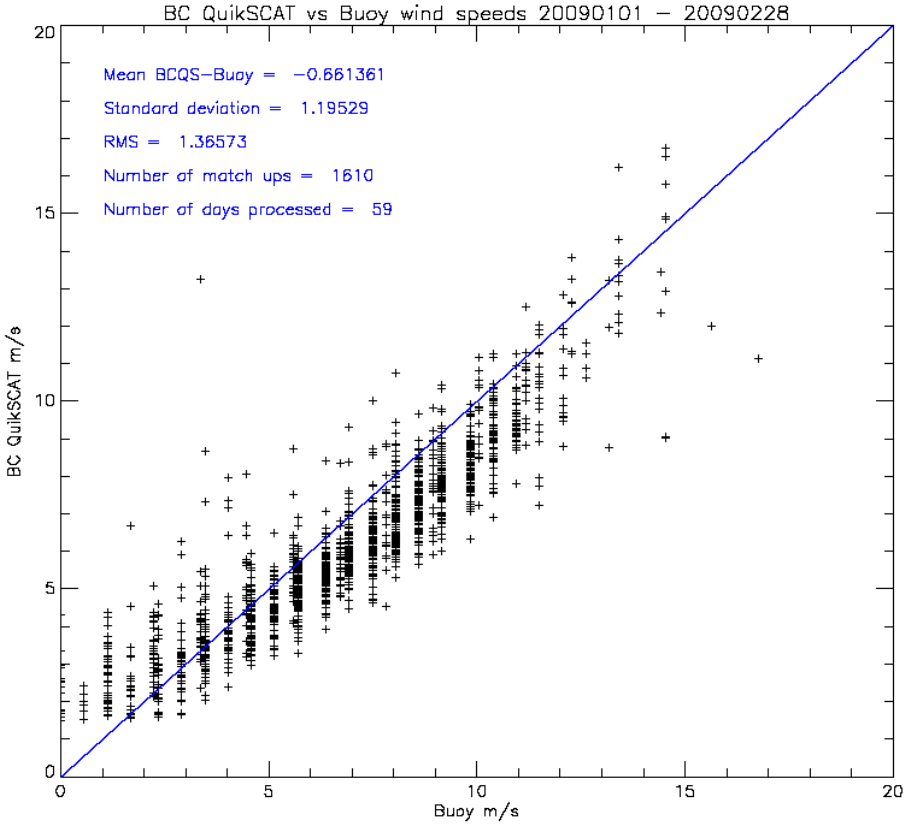


Figure 3.2.2 Moored buoy wind speed observations plotted versus bias-corrected QuikSCAT wind speeds.

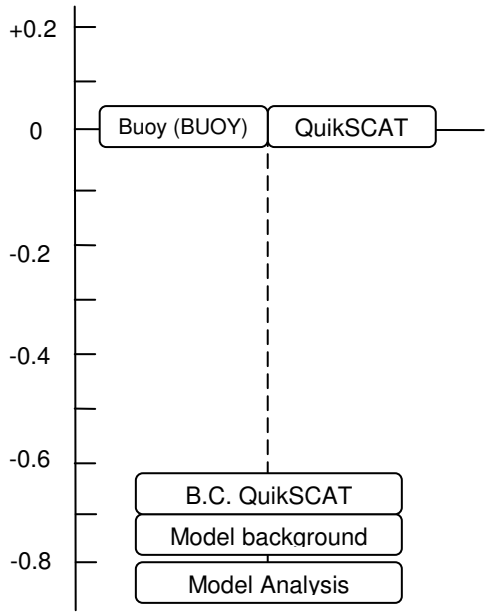


Figure 3.2.3 Schematic of the bias with respect to the moored buoy wind speeds. Note that here 'QuikSCAT' refers to the uncorrected winds..

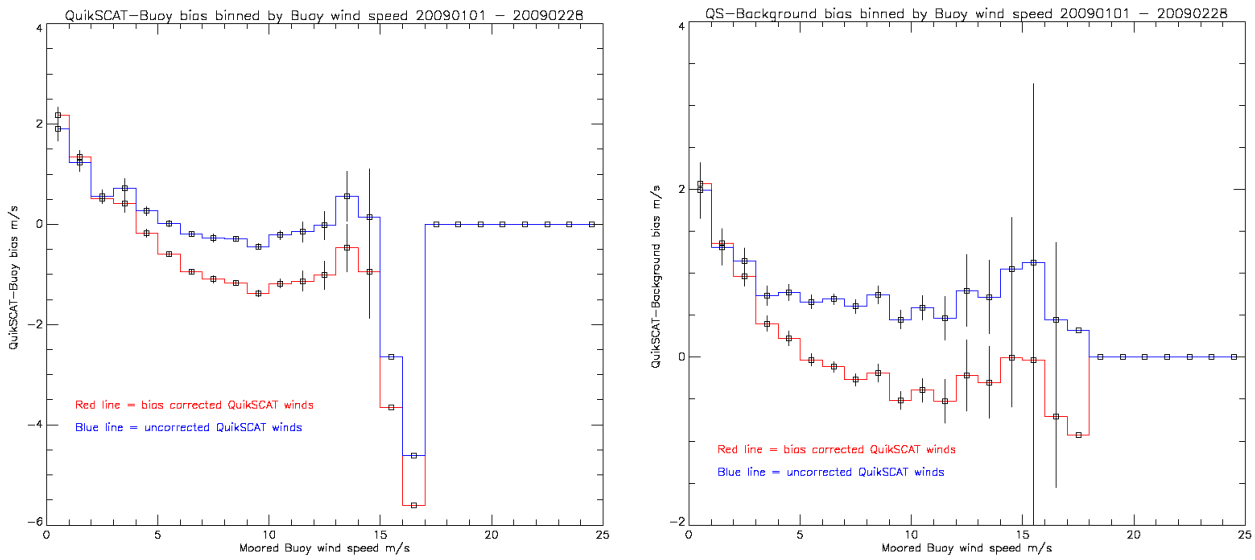


Figure 3.2.4 a) Left. Plot showing the bias in buoy wind speed for both uncorrected and bias-corrected QuikSCAT, binned by buoy wind speed. b) Right. Plotted as in a) except this time showing the bias with respect to the background wind speed.

4. Comparison of QuikSCAT with SHIP reports

In this section QuikSCAT wind speeds are compared with fixed platforms, rigs, ships and buoys reporting in SHIP code format. This comparison will be similar in nature to that performed in FRTR 472 (Keogh, 2005) which looked at data from fixed platforms, buoys and light vessels, although no adjustment was made for the discrepancy in anemometer heights.

The data considered here have all been transmitted in the SHIP code format of the WMO. Individual ships can be identified from their unique call sign which is similar to a buoy's WMO number except that it includes at least one letter character. Wind observations from ships are more prevalent in the Northern Hemisphere and are either recorded manually or automatically. Automated wind observations are performed hourly whereas manual ship observations are usually reported every 6 hours, such that even though only a small proportion of ships are automated (6%) they provide over a quarter of ship reports in total. Nearly 1/3rd of manual ship reports still indicate use of visual estimates taken from the Beaufort force, i.e. visual sea state.

Some reported ship winds do not have the ship velocity correctly removed which will on average tend to increase the reported speed (actually reporting relative winds). For many ship reports we don't know the anemometer height, and worse, anemometers may be poorly sited introducing variable sheltering effects. Yelland et al.(1998), used computational fluid dynamics to simulate the air flow over two research ships and found accelerated flow (i.e. measurement would be an overestimate) of about 6% at the mainmast anemometer and decelerated flow by up to 3% at the bow anemometer.

As was the case in section 3, the drifter buoy reports were rejected leaving only the moored buoys reporting in SHIP code for investigation. The moored buoys here are mainly located in coastal waters or on continental shelves, unlike the moored buoys reporting in BUOY code which are chiefly located in deep water near the tropics. The data from fixed platforms and rigs connected with the oil industry are primarily located in the North Sea and there are also five light vessels reporting in the English Channel.

4.1 Method

The period of analysis was from 1st January to 28th February 2009 (59 days), as was the case for the moored buoy comparison in section 3. Data in SHIP code format was read in from Bruce Ingleby's archive located at '/data/local/frbi/marine/frommetdb/Global' for January and February and split into daily files for ease of processing. The data had already been thinned and had land and track checks performed on it. The thinning mean that there was at least an hour between reports from the same station and the land check removed any data that was very close to the coast, inland (e.g. lakes of North America) or in ports. The track check examined a month's position data for each station and then rejected reports if the implied speed between two consecutive report positions was too high.

Ship anemometer heights typically vary between 8-60m above mean sea level and this meant that potentially each ship wind speed needed individual adjustment. This was done through the use of ship metadata from WMO Publication No. 47 (WMO Pub 47) which includes, amongst other variables, information on vessel type and anemometer height. Each unique ship call sign from the data read in was examined to see if it could be matched to a ship record in WMO Pub 47. If a match was found then the anemometer height (if present) associated with that ship callsign could be set. If the anemometer height was missing but the vessel type was present then an estimated anemometer height was set using an average for that particular vessel (e.g. CS = container ship with an estimated height of 37m). If no record was found in WMO Pub 47 for a particular call sign (roughly 25% of ships reporting on the GTS are not listed in WMO Pub 47) then a default anemometer height of 30m was set. All ship wind speeds were then adjusted to

10m using the anemometer height associated with the report and the logarithmic profile of equation 1.

Rigs and platforms with winds already adjusted to 10m were distinguished through a list of known identifiers and no further processing was required. Buoys' reporting in SHIP code fall into several categories and the main source of information on these is from the website of the deploying agency. The five light vessels reporting in the English Channel were identified by their WMO number and their anemometer height set to 15m. A set of US buoys could also be identified with anemometers either at 10m (no adjustment needed) or at an unknown height, in which case they were set to a height of 5m. European buoys identified by their latitude and longitude were set to a height of 3m and all other buoys were set to 5m anemometer heights. Buoy and rig winds from stations not already at 10m were then adjusted in the usual way using equation 1.

Unless otherwise stated, the term 'SHIP' will be used to refer to all the data in SHIP code format: rigs/platforms, manual ships, automate ships and buoys.

The same procedure as in section 3.1 was used to collocate the SHIP data with QuikSCAT (satellite observation occurring within +/- 30 minutes and 25km), plus an additional check to remove winds close to the coast. In this instance the final quality control step detected and removed 42 duplicate SHIP observations leaving 7945 matchups for the period. The global distribution of these matchups can be seen in Figure 4.1.1. The plot shows a high concentration of buoys and rigs around the US coast and the North Sea respectively, whilst there are many more ships in the Northern Hemisphere than in the Southern Hemisphere.

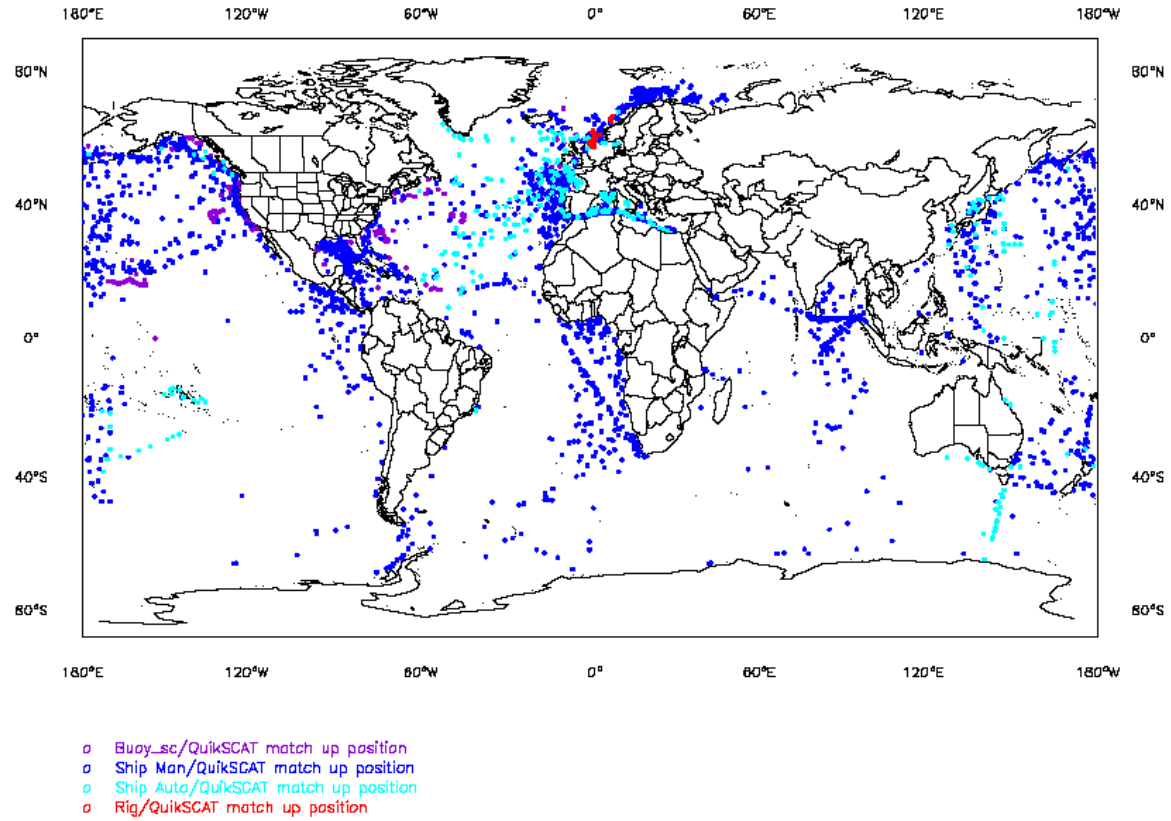


Figure 4.1.1 Coverage of QuikSCAT and SHIP matchup points. Note the different colours are for indication only as some over-plotting of points is inevitable.

4.2 QuikSCAT and SHIP statistics

The mean matchup distance of 16.7km for all 7945 QuikSCAT-SHIP collocations is consistent with that found for the altimeter and buoy collocations in sections 2 and 3. The mean absolute time difference of nearly 17 minutes is slightly longer than in the previous comparisons (observations will usually be an average taken over 10 minutes anyway, ending on the hour). The distribution of collocated SHIP wind speed is given in Figure 4.2.1 and shows an average wind speed similar to the altimeter winds at 8.5m/s - over 1.5m/s faster than was found for the moored buoys which were confined to the tropics. Although the majority of winds again occur below 15m/s, there appears to be a marginally heavier tail to the distribution when compared to Figure 2.2.1. This indicates the presence of some faster winds in this comparison, probably due to increased coverage in the storm track regions of the Northern Hemisphere. A summary of the main statistics for the QuikSCAT and SHIP comparison is shown in Table 4.2.1.

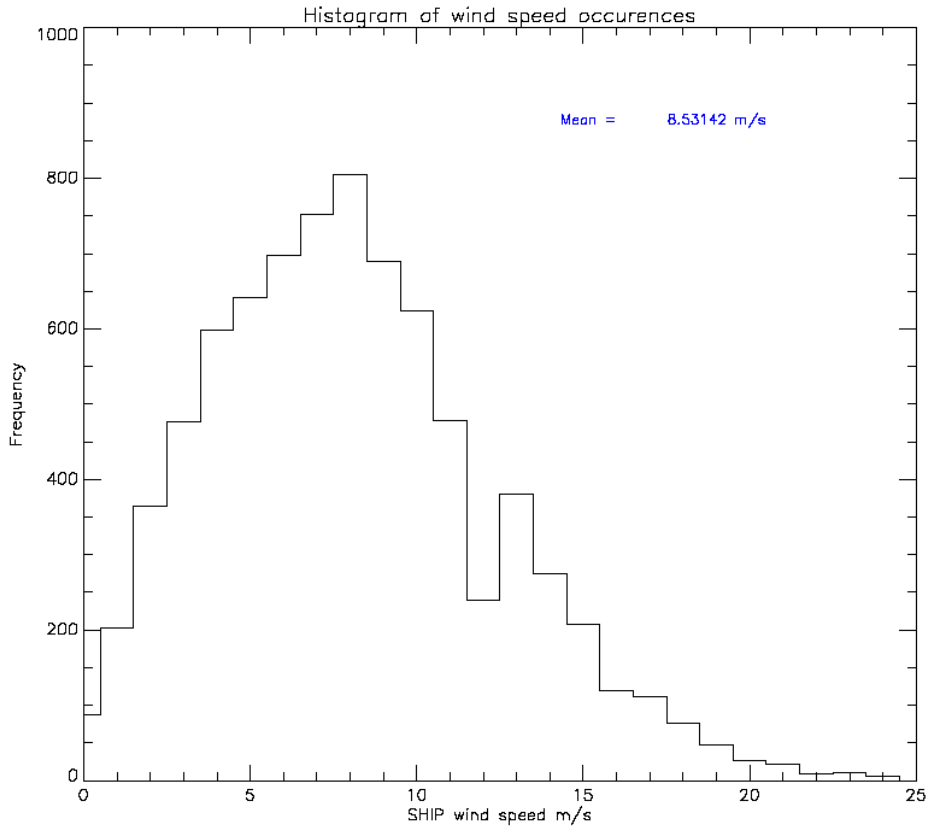


Figure 4.2.1 Distribution of ship/platform/buoy wind speeds for the period.

Component	Std Dev m/s	Mean m/s	RMS m/s
QS - SHIP	1.905	0.476	1.964
BCQS - SHIP	1.888	-0.324	1.915
SHIP - Bg	2.088	0.314	2.112
SHIP - A	2.024	0.463	2.076
QS - A	1.429	0.939	1.709
BCQS - A	1.368	0.139	1.375
QS - Bg	1.409	0.790	1.615
BCQS - Bg	1.354	-0.010	1.354

Key:

- QS = uncorrected QuikSCAT
- BCQS= bias-corrected QuikSCAT
- SHIP= ship/platform/buoy
- Bg = model background wind speed
- A = model analysis wind speed

Table 4.2.1 Summary of results for QuikSCAT-ship/platform/buoy collocations.

The results in Table 4.2.1 show that this set of collocations have a higher RMS and standard deviation than was present in the altimeter and moored buoy comparisons (see Tables 2.2, 3.2), particularly for the ‘SHIP’ components. There is a less strong agreement between the uncorrected QuikSCAT and SHIP wind speeds, with the satellite winds biased fast by a mean of +0.48m/s (Figure 4.2.2). The bias-corrected winds exhibit a mean bias of -0.32m/s with respect to the SHIP winds (Figure 4.2.3) meaning the SHIP winds in fact lie closer to the middle point between the two QuikSCAT cases.

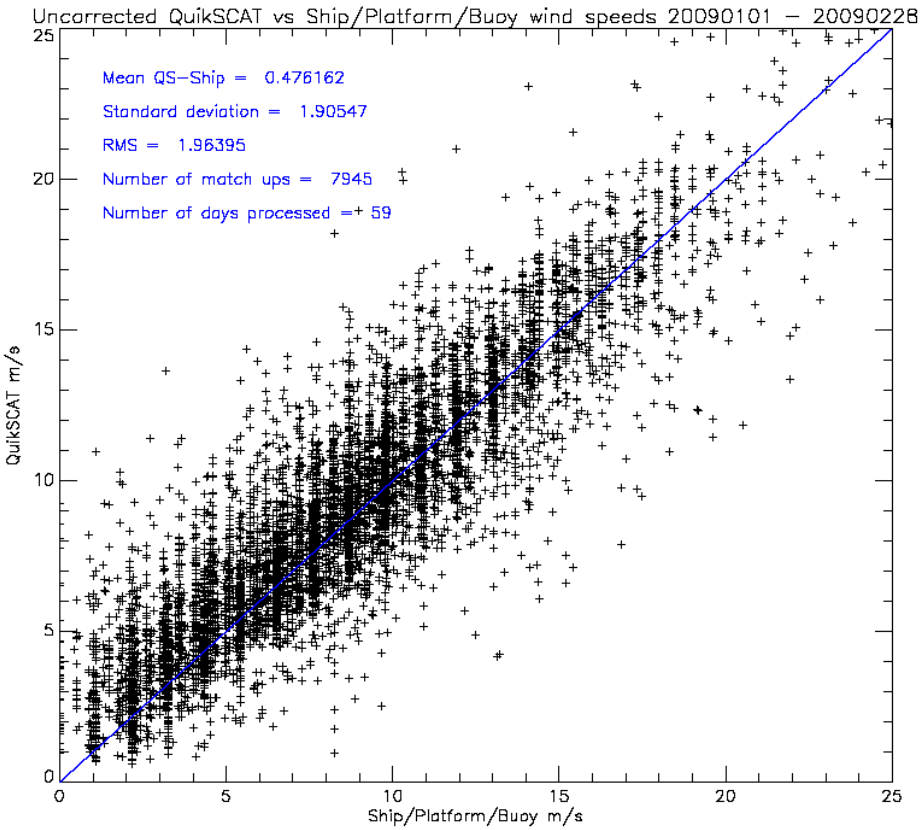


Figure 4.2.2 SHIP wind speed observations plotted versus uncorrected QuikSCAT wind speeds.

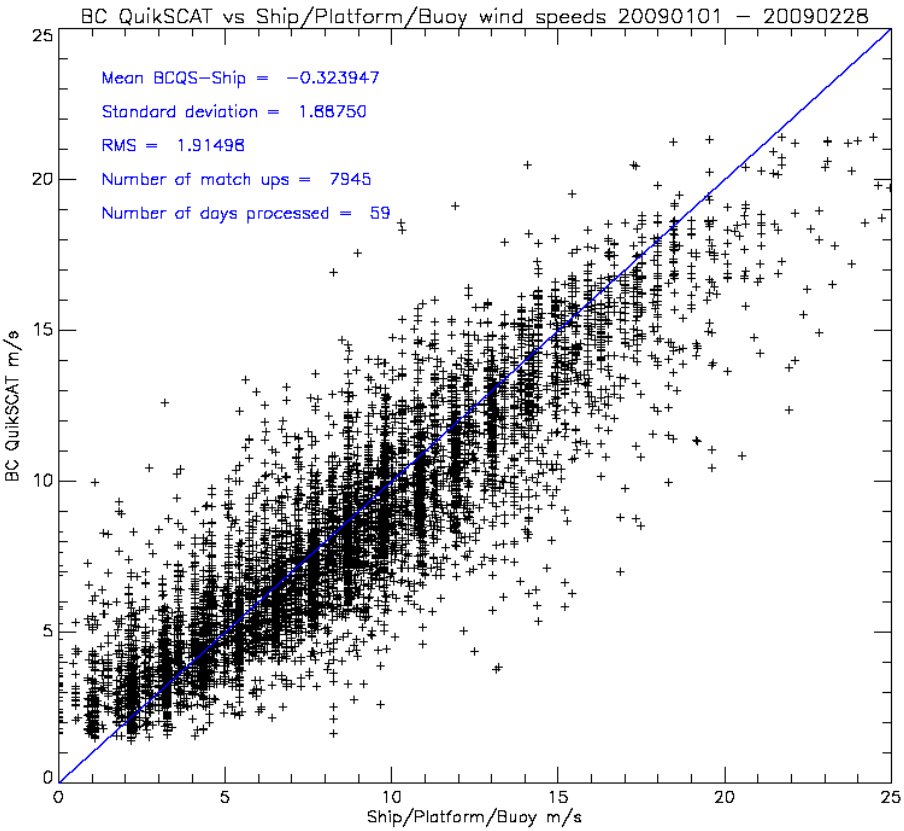


Figure 4.2.3 SHIP wind speed observations plotted versus bias-corrected QuikSCAT wind speeds

Figure 4.2.4a shows that the QuikSCAT-SHIP wind speed bias for the collocations becomes increasingly negative with increasing SHIP wind speed - perhaps an indication that QuikSCAT is underestimating the faster winds (though the number of winds in these bins are sparse). Figure 4.2.4b demonstrates that the bias for QuikSCAT with regards to the background speed is fairly uniform across the range 2-20m/s in the uncorrected case. The bias correction applied to QuikSCAT means that it agrees very well with the background in the range 5-15m/s, but is significantly overcorrecting the winds exceeding 20m/s.

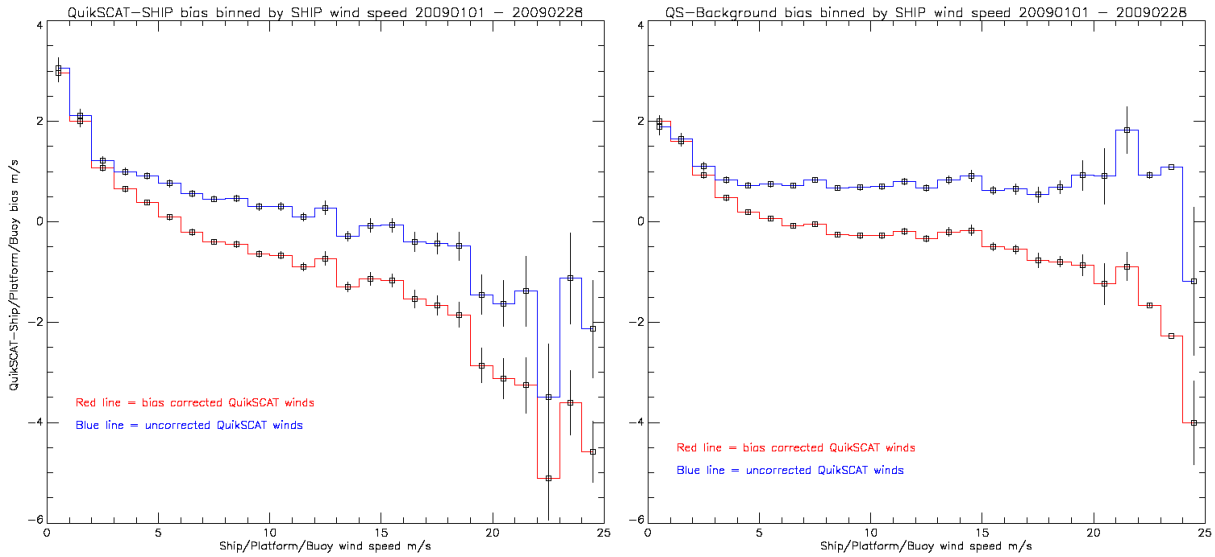


Figure 4.2.4 a) Left. Plot showing the bias in SHIP wind speed for both uncorrected and bias-corrected QuikSCAT, binned by SHIP wind speed. b) Right. Plotted as in a) except this time showing the bias with respect to the background wind speed.

The SHIP observations are biased fast compared to the model background by 0.31m/s with a ratio of 1.10 between the two suggesting the background is 10% too weak. To compare the results further the statistics were broken down by the different SHIP observation types as shown in Table 4.2.2. As in section 3 the uncorrected QuikSCAT winds show good agreement versus the buoys with near zero bias and smaller standard deviation. In contrast there is a larger degree of uncertainty in the manual and automated ship reports. A schematic of biases with respect to the manual ship, automated ship and buoy reports is given in Figure 4.2.5.

Observation (O)		QS-O	BCQS-O	O-Bg (ratio)	O-Bg ratio Ingleby	Count
manual ship:	mean	0.169	-0.596	0.552 (1.17)	1.19	2428
	st.dev	2.33	2.31	2.52		
auto ship:	mean	0.600	-0.168	0.085 (1.08)	1.09	394
	st.dev	1.97	1.94	2.08		
platform/rig:	mean	1.647	0.728	-0.506 (0.94)	1.06	1715
	st.dev	1.71	1.74	1.85		
buoy as ship:	mean	0.091	-0.678	0.583 (1.13)	1.12	3408
	st.dev	1.33	1.35	1.73		

Key:
QS = uncorrected QuikSCAT
BCQS= bias-corrected QuikSCAT
Bg = model background

Table 4.2.2 Statistics broken down by SHIP observation type.

Ingleby's report found that manual and automated ship reports were 19% and 9% stronger than the background respectively, which shows strong agreement with the results for the collocations here at 17% and 8% respectively. The buoys in ship code are 13% stronger than the background for the collocations which is again in strong agreement with Ingleby's findings at 12%. This is encouraging as only 7945 matchups were used for these statistics compared to the millions that made up Ingleby's comparison for the whole of 2007. However there is one anomaly and that is the statistics for the fixed platform and rigs. Table 4.2.2 shows the platforms/rigs are 6% weaker compared to the background when they were 6% stronger in Ingleby's report. Consequently the uncorrected QuikSCAT winds here have a fast bias of +1.6m/s with respect to the fixed platforms, which is large even in comparison to Keogh's previous work which gave a fast bias of 1.1m/s. If we exclude the platform/rig winds then the uncorrected QuikSCAT–SHIP winds bias falls to just 0.15m/s, whilst the bias-corrected winds become more negative at -0.61m/s. These results are very similar to those found for the radar altimeter comparison in section 2, providing further evidence that the current bias correction coefficients are overcorrecting to some extent and could do better.

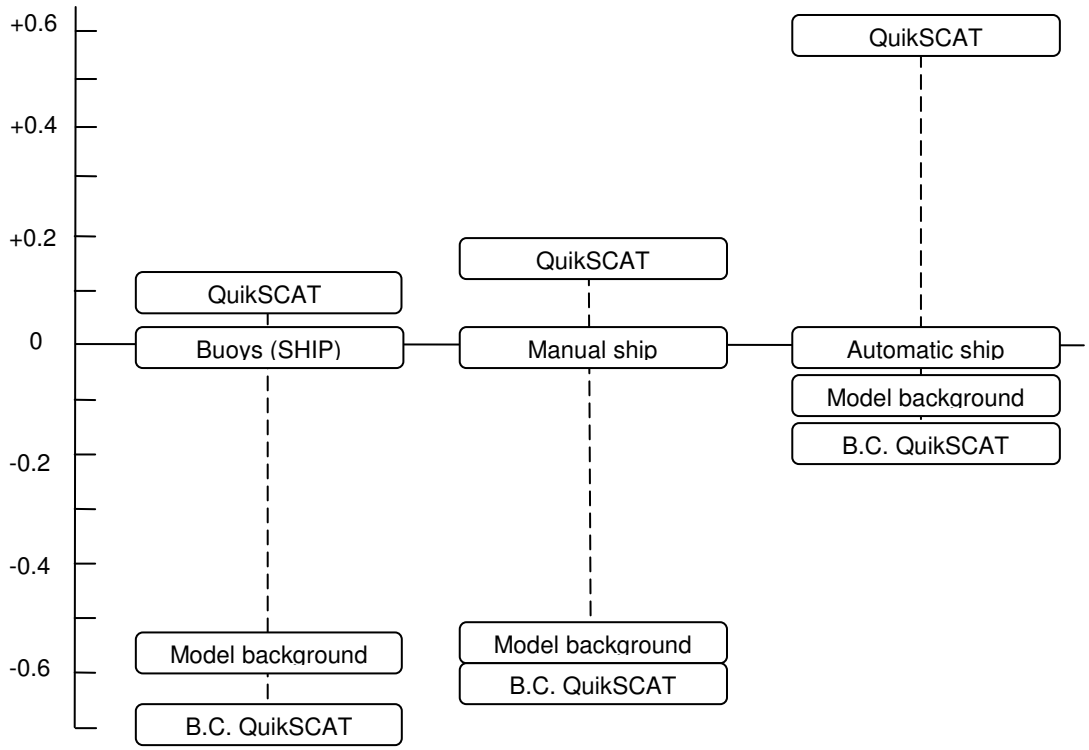


Figure 4.2.5 Schematic of biases with respect to the SHIP observation types. Note that here 'QuikSCAT' refers to the uncorrected winds.

5 New QuikSCAT bias correction

The current set of bias correction coefficients has been operational since 14th June 2005. The evidence presented here in sections 2, 3 and 4 has in fact shown that, in the majority of cases, the uncorrected QuikSCAT winds are in better agreement with the winds from the other marine wind observation types. The bias-corrected winds agree better with the background although the model background itself may be on average 10% too weak as shown by the comparisons presented in this report. We have no way of knowing which of the comparison sources, QuikSCAT or model background is closest to the 'truth'. However the results of this report suggest that the current bias correction could be performing better and a possible new correction polynomial is calculated in this section.

5.1 Method

Two months (59 days) of QuikSCAT wind data along with the Met Office model data merged back from MetDB were used to calculate the new bias correction coefficients. Although this period covers only January and February, the global coverage of the Seawinds satellite should negate any seasonal dependencies. For each day of the study the QuikSCAT wind speeds were binned by both the observed wind speed and the model background wind speed in 1m/s bins between 0 and 25 m/s (current operational upper bound). The method used to bin the data is important, as for unbiased Gaussian error distributions computing the mean of a variable y for a fixed bin of a variable x (bin-average analysis) in general reveals a pseudo bias that depends on the error characteristics of x (Stoffelen, 1998). Therefore the approach used here was to bin the data first by observation value, then by model background value and then fit a polynomial to the two resulting bias curves.

The current coefficients were calculated in FRTR 472 using model analysis values rather the background and there pros and cons to either approach. The analysis winds should be closer to 'truth' and are the starting point for the forecast but will contain the old model and observation biases combined. This study regresses against the model background as the biases are more independent and more aligned to the zero-bias assumption in Variational Data Assimilation (VAR).

As can be seen in Figure 5.1.1 the current bias correction (red) does have a positive impact compared to the uncorrected case (black). An ideal result would be if the data points were close to, and symmetrical about the line $y=x$ and clearly that is no longer the case for either of the two sets of curves (but was true for the current coefficients at the time they were calculated). For the uncorrected winds, the points lie to the right of the line which is consistent with the stronger observed winds (with respect to the background) seen throughout this study. The opposite is true for the current bias correction, with the majority of points plotted to the left of the line as a result of the overly zealous speed correction being applied. Compare this plot to figure 4.3.1 of FRTR 472 (here the current coefficients are the 'new' ones plotted in green) and some quite significant differences can be discerned and are unlikely to be due to the use of analysis winds. Most notable is the reduction of the QuikSCAT (uncorrected) saturation effect for wind speeds in excess of 20m/s, with the tail in the data now only present in the most extreme background bin.

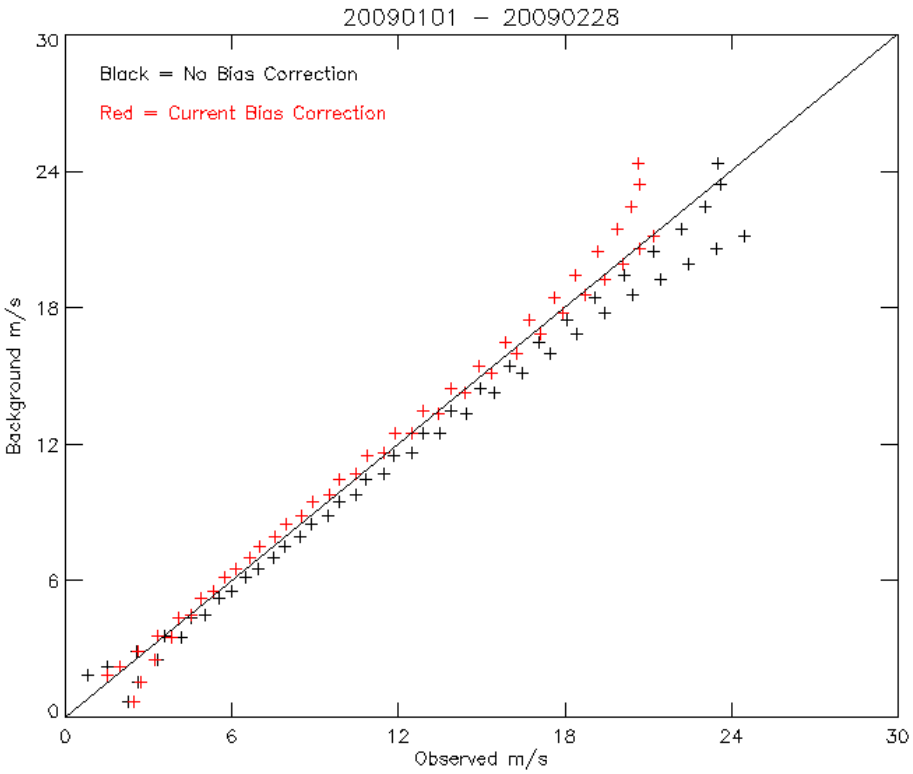


Figure 5.1.1 Plot of bin-average uncorrected and current bias-corrected QuikSCAT winds – binning by both the observed and background speed.

5.2 New polynomial fit

The new polynomial fit is of the form:

$$y = c_0 + c_1 x + c_2 x^2 + c_3 x^3, \quad c_i \in R$$

where $x =$ observed QuikSCAT wind speed, $y =$ bias-corrected wind speed. Initially this was performed using the full set of coefficients ($c_i \neq 0 \ \forall i$) yielding the new set of parameters given below.

Current: $[c_0, c_1, c_2, c_3]$ = [1.11220, 0.488799, 0.0418553, -0.00115649]

New: $[c_0, c_1, c_2, c_3]$ = [0.202537, 0.839771, 0.0105109, -0.000291411]

As the quadratic and cubic coefficients are very near zero they can be tested to see whether the values of c_2, c_3 are significant or whether a more simple (linear) correction would be appropriate. Given below are some summary statistics for this particular polynomial fit.

Parameter covariance matrix:

$$\Sigma = \begin{pmatrix} 0.500185 & -0.151499 & 0.012240 & -0.000288 \\ -0.151499 & 0.055369 & -0.004860 & 0.000120 \\ 0.012240 & -0.004860 & 0.000449 & -1.14720e-05 \\ -0.000288 & 0.000120 & -1.14720e-05 & 3.00038e-07 \end{pmatrix}$$

Parameter 1-sigma (standard deviation) uncertainty estimates:

$$\sigma_0 = 0.707238 \quad \sigma_1 = 0.235305 \quad \sigma_2 = 0.021197 \quad \sigma_3 = 0.000548$$

Standard error = 0.726

To identify the significance of the parameters c_2 and c_3 we can test the null hypothesis that the parameters are equal to zero. If we assume that we are fitting the polynomial

$$y_i = c_0 + c_1 x_i + c_2 x_i^{\ 2} + c_3 x_i^{\ 3} + \varepsilon_i$$

where c_0, c_1, c_2, c_3 are the unknown parameters and ε_i are independent normally distributed residuals (random errors), with expected value $E(\varepsilon_i) = 0$ and unknown variance. Then

$$\frac{(c_i - 0)\sqrt{n-2}}{\sqrt{\sum_{i=1}^{n} \varepsilon_i^2 \Big/ \sum_{i=1}^{n} \left(x_i - \bar{x}\right)^2}} = \frac{c_i}{\sigma_i}$$

has a student's t-distribution with $n - 2$ degrees of freedom. By comparing this test statistic with the student's t distribution at the 95% significance level (two-tailed test) we can determine the significance of the parameters c_2 and c_3. The hypothesis under test is H_0: $c_i = 0$, H_1: $c_i \neq 0$ for i=2,3.

$$\left|\frac{c_2}{\sigma_2}\right| = 0.495861, \quad \left|\frac{c_3}{\sigma_3}\right| = 0.532007$$

$$t_{0.975,\, n-2} = 2.011$$

Thus the quadratic and cubic coefficients are not statistically significant at this level as their test statistic does not exceed 2.011.

As a result of this the polynomial fit was performed once more but this time with the coefficients for the quadratic and cubic term set to zero yielding the parameters given below.

New: $[c_0, c_1]$ = [-0.00567466, 0.940110] with $c_2, c_3 = 0$

Parameter covariance matrix:

$$\Sigma = \begin{pmatrix} 0.084749 & -0.005078 \\ -0.005078 & 0.000398 \end{pmatrix}$$

Parameter 1-sigma (standard deviation) uncertainty estimates:

$$\sigma_0 = 0.291116 \qquad \sigma_1 = 0.0199554$$

Standard error = 0.716

The removal of the quadratic and cubic terms has reduced the uncertainty in the remaining two parameters and has resulted in a marginal reduction in the standard error of the fit. Therefore it is the simpler linear correction which provides the better fit and

$$[c_0, c_1, c_2, c_3] = [-0.00567466,\ 0.940110,\ 0,\ 0]$$

the preferred set of coefficients for inclusion in OPS. Figure 5.2.1 shows the form of the new polynomial fit which lies between the data binned by observation and background speed. As can be seen in Figure 5.2.2 the new polynomial fit (green) looks much closer to the ideal case with the points symmetric about, and close to the line $y=x$ with the exception of the tail artefact discussed earlier in section 5.

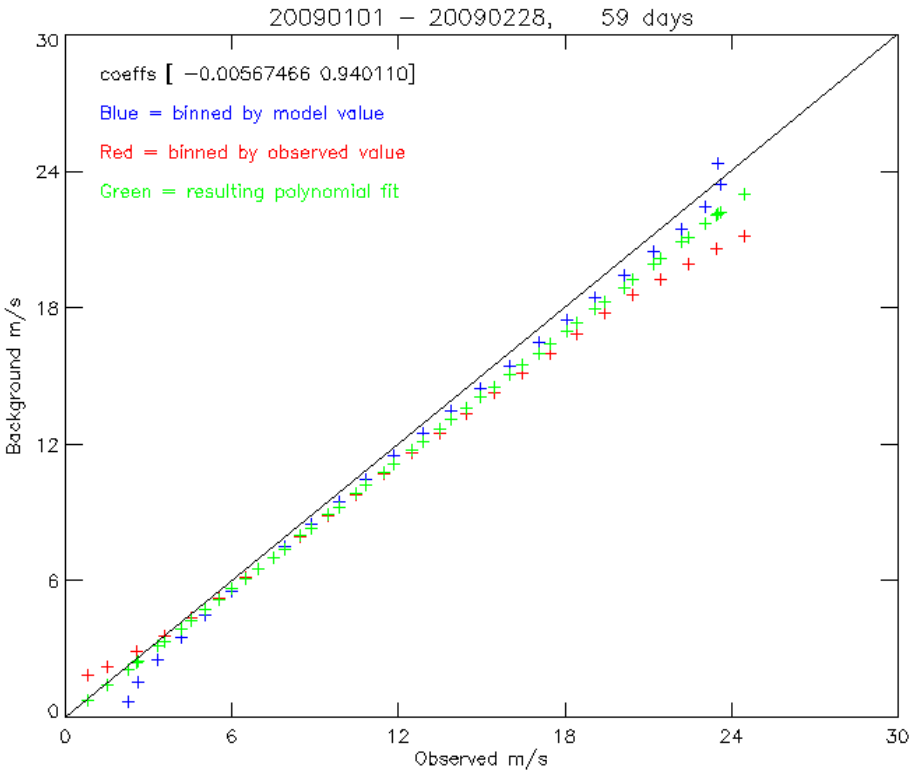


Figure 5.2.1 Plot of the new polynomial fit constructed with the coefficients given.

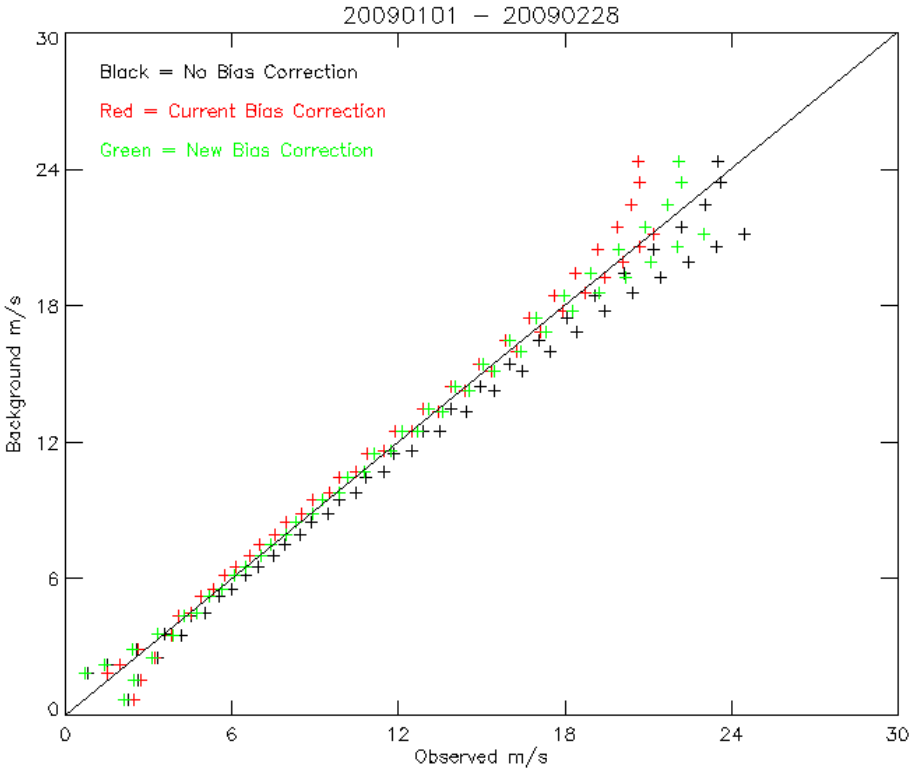


Figure 5.2.2 Plot of bin-average uncorrected, current bias-corrected and new bias-corrected QuikSCAT winds – binning by both the observed and background speed.

To see the impact of the polynomial fit, the data for January and February was re-examined using the new set of bias correction coefficients alongside the current ones. The mean and standard deviation O-B bias for the entire period (daily average) is given in Table 5.1 below. This confirms

QuikSCAT winds	st.dev	mean
Uncorrected	1.30	0.48
Current bias correction	1.25	-0.27
New bias correction	1.26	-0.01

Table 5.1 Standard deviation and mean O-B over the 59 day period.

the good fit already seen in Figure 5.2.2, with near zero bias and only a marginal increase in standard deviation for the new simple linear correction. The O-B bias for the uncorrected winds increases monotonically with increasing observation wind speed as shown in Figure 5.2.3. The newly calculated coefficients show a positive impact in comparison, with near zero bias in the range 4-15m/s and then an increasing bias in the faster bins consistent with the linear correction applied. The current correction appears to outperform the new coefficients at high observation speed (if we are regarding the background as 'truth') which is likely due to the cubic nature of its polynomial fit. However, when we bin by the background speed as in Figure 5.2.4 the opposite is true.

Both figures 5.2.3 and 5.2.4 show the heavy correction applied by the current coefficients in the range 20-25m/s compared to the uncorrected case. Figure 5.2.4 also shows a fairly uniform bias for the uncorrected winds in the range 5-20m/s and the new coefficients performing better than the current coefficients across the board. In both plots the new bias correction appears to be a 'halfway house' scenario between the current and uncorrected cases.

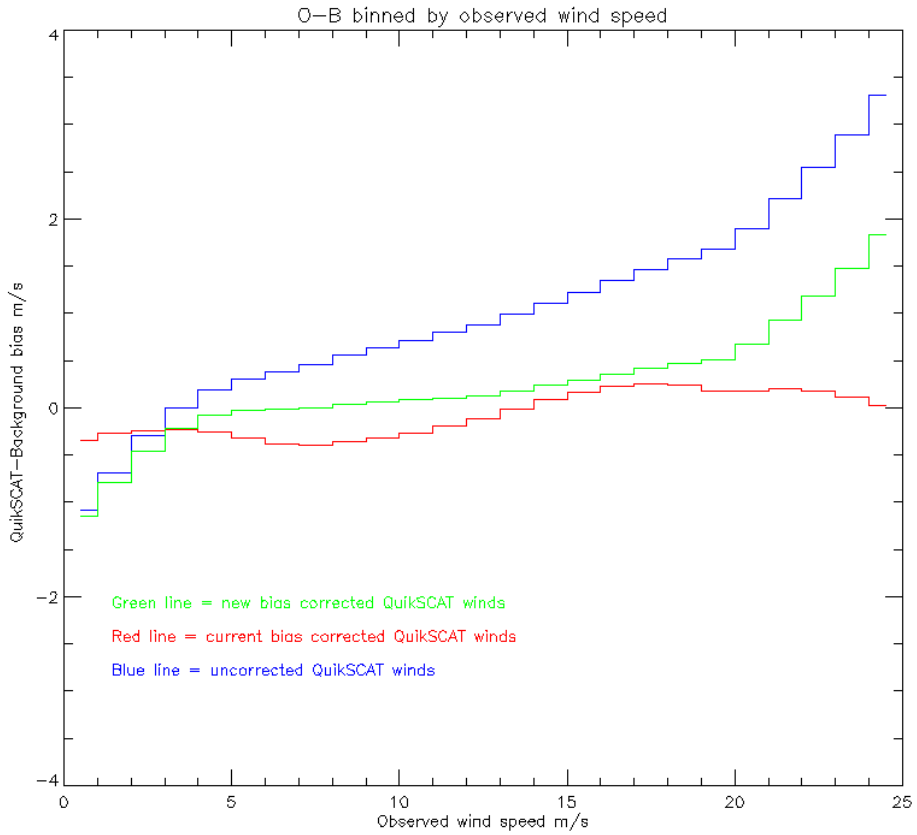


Figure 5.2.3 Histogram of O-B binned by the observed wind speed for the uncorrected, current bias-corrected and new bias-corrected winds.

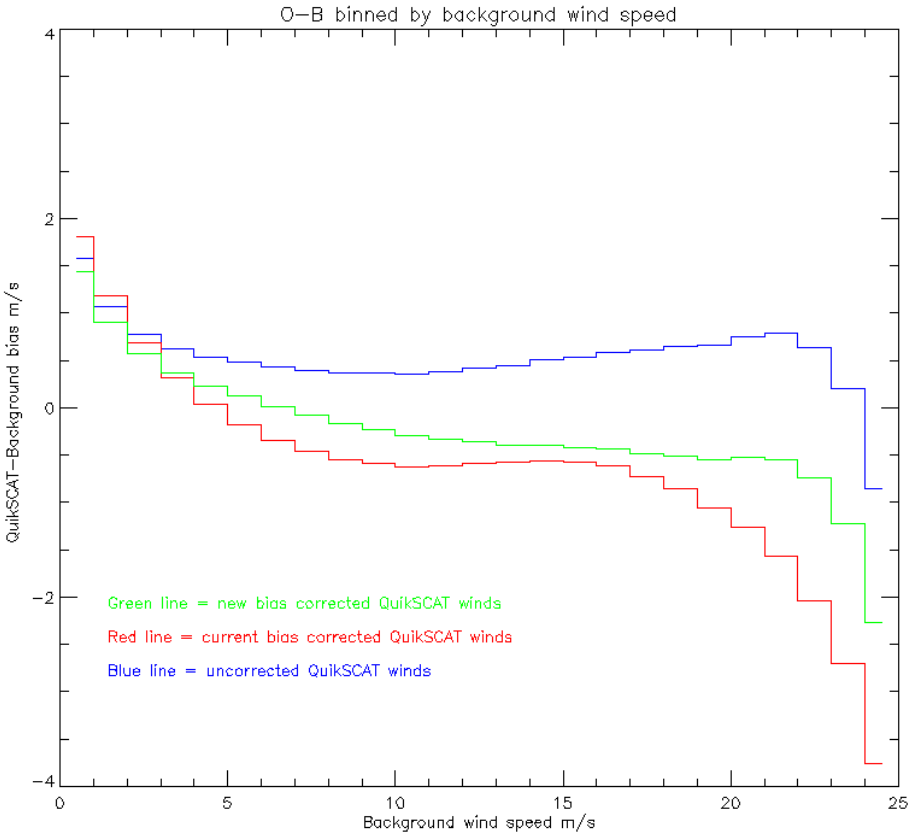


Figure 5.2.4 Histogram of O-B binned by the model background wind speed for the uncorrected, current bias-corrected and new bias-corrected winds.

It is worth noting that the bias correction has been calculated for the operational swath only. The QuikSCAT swath is 76 nodes in width but only nodes 11-28 and 49-65 are used by the Met Office for NWP. This sweet region is illustrated in Figure 5.2.5.

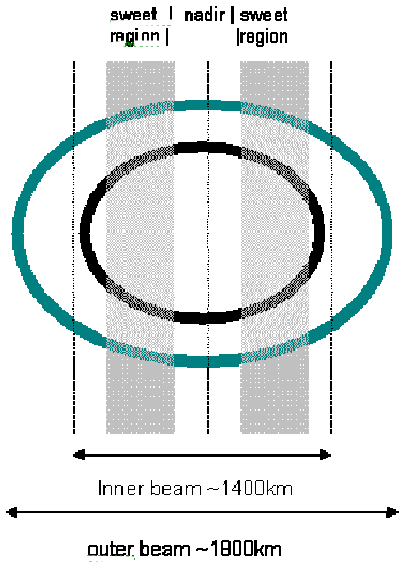


Figure 5.2.5 The QuikSCAT swath.

6. NESDIS Seawinds test data

The current QuikSCAT level 2 BUFR data from NOAA/NESDIS has been assimilated at the Met Office since 2002. QuikSCAT is a scanning scatterometer that uses a microwave wavelength of 2.1cm (Ku-band) which is susceptible to rain contamination. Quality control to eliminate as much rain contaminated data as possible has led to over-flagging of winds and to address this a new product has been released for testing by NESDIS. In March 2008 an assimilation trial looked at the impact of this improved product on the Met Office global forecast (Keogh et al, 2008) and found an improvement in tropical winds particularly in areas where there is significant rainfall. Overall the trial demonstrated that the new product makes a suitable replacement for the current one and it was thought prudent to prepare a potential bias correction for this product for when the current one is withdrawn.

QuikSCAT test data was accumulated for 25 days during the period 27 February 2009 to 23 March 2009 and bias correction coefficients were calculated in similar fashion to section 5. The results are given below and a plot of the data binned by observation and model value is shown in Figure 6.1 along with the linear polynomial fit.

cubic fit: $[c_0, c_1, c_2, c_3]$ = [-0.649108, 1.04250, -0.00170132, -0.000117334]

linear fit: $[c_0, c_1]$ = [-0.0312701, 0.928808]

The linear coefficients are fairly similar to those calculated in section 5.2. Daily monitoring of this test data has shown an O-B bias comparable to that of Ascat (currently uncorrected) so initially no bias correction may be needed subject to further monitoring of the situation. However, it should be noted that the monitored test data hasn't been thinned within OPS compared to the current operational QuikSCAT stream.

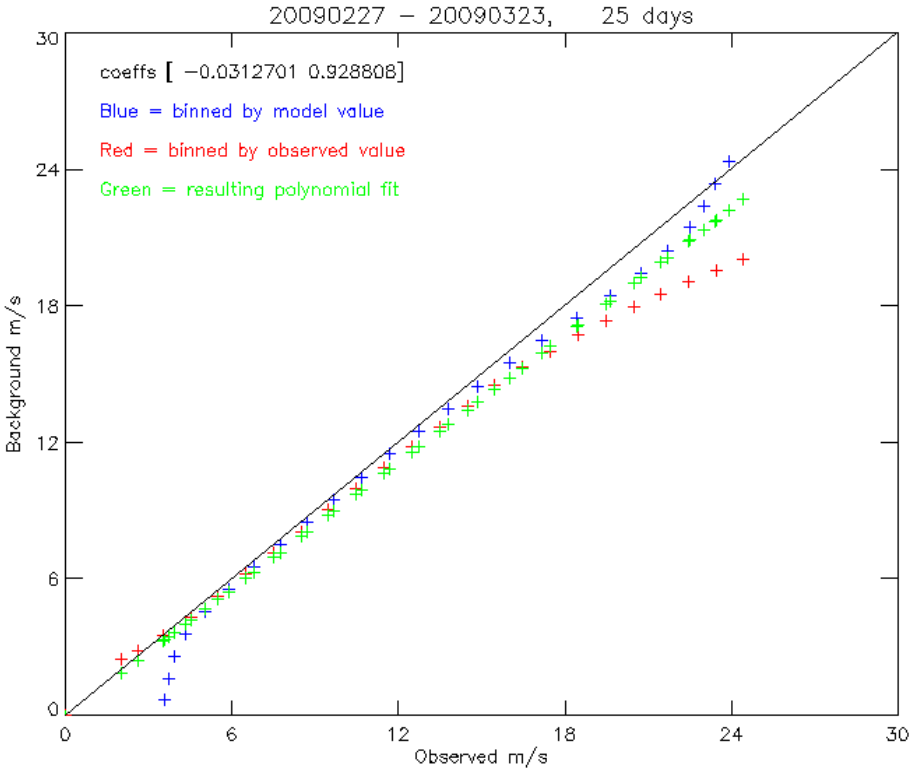


Figure 6.1 Plot of the new polynomial fit for the 'test' data.

7. Conclusions and recommendations

This report has compared the performance of QuikSCAT wind speeds with and without the current operational bias correction applied. In most cases it is the uncorrected, rather than the bias-corrected, QuikSCAT wind speeds which agree better with the other ocean wind observations. The respective biases are:

Component	Uncorrected	Bias-corrected
QuikSCAT - ERS altimeter	+0.16	-0.64
QuikSCAT - moored buoys (BUOY)	+0.01	-0.66
QuikSCAT – SHIP* (shipm,shipa,buoy)	+0.15	-0.61
QuikSCAT - ship manual	+0.17	-0.60
QuikSCAT - ship auto	+0.60	-0.17
QuikSCAT - buoys (SHIP)	+0.09	-0.68

* Rig/fixed ocean platform wind speeds showed poor agreement with the satellite winds.

The model background has been found to be 4% too weak compared to the altimeter winds from ERS-2 and 17% too weak relative to deep water tropical moored buoys. SHIP observations on average suggest that the model background is 10% too weak with manual ships, automated ships and buoys in ship code coming in at 17%, 8% and 13% respectively. Unsurprisingly the bias-corrected QuikSCAT wind speeds show stronger agreement with the model background, which we know is roughly 8% weak relative to the uncorrected QuikSCAT winds. However we have no way of knowing which of the comparison sources is closer to the actual true wind speed. It is possible that the 'truth' in fact lies somewhere in between the observations (scatterometer, altimeter, buoys, ships) and the model background field.

The comparison studies showed evidence that the current QuikSCAT bias correction coefficients are overcorrecting to some extent and could do better. A new set of coefficients was calculated with a simpler linear polynomial shown to provide the best fit to the data binned both by background and observation speed. The new coefficients have been shown to reduce the correction applied resulting in a mean O-B of approximately -0.01m/s compared to the current bias in the region of -0.3m/s.

There does seem to be evidence that the background winds are currently too weak and from this perspective one could argue that we shouldn't be bias correcting QuikSCAT against the model at all. The question is should we be aiming for near zero O-B bias for the sake of VAR or should we leave some residual positive bias to 'bootstrap' the model to higher speeds and if so, by how much? What is clear is that the current bias correction is no longer performing as well as it could be. Therefore the new coefficients as calculated in section 5.2 are recommended for inclusion in the next available operational change via the scatterometer (scatwind) namelist.

It is important to remember that any changes to surface winds will have a downstream impact. If we believe that the ocean surface model winds are presently biased low then this may be translating into a low bias in wave heights. However, that is not currently the case as Met Office model significant wave heights are currently biased slightly positive versus buoys in the latest ECMWF intercomparison (Figure 7.1). This could in part be due to the fact that wave heights are not entirely determined by the local wind speed, but also depend upon swell generated remotely. If we 'improve' the wind speed bias then this could have a negative impact on the wave height bias meaning some retuning of the wave model may be required. The main requirement from a wave modelling perspective is for the wind to evolve in a stable way and over timescales that allow them to adapt to any changes (A.Saulter and A.Hines, pers. comm. 2009).

Ideally the accuracy of the wind over the ocean needs to be improved over time (and so avoiding the need to tune models to account for biases) particularly with the move from 40km to 25km global resolution scheduled for implementation in Parallel Suite 23 ~ February 2010.

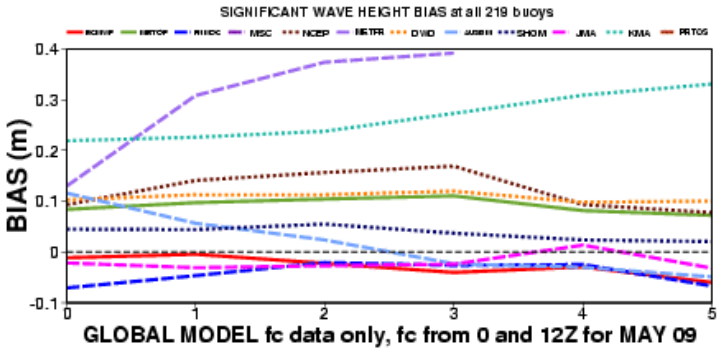


Figure 7.1 Plot of significant wave height bias for all buoys versus the Met Office global model (green line) for May 2009 . Operational Wave Forecast Verification Exchange.

8. References

Benschop, H. 1996. Windsnelheidsmetingen op zeestations en kuststations: herleiding waarden windsnelheid naar 10-meter niveau. Koninklijk Nederlands Meteorologisch Instituut Technical Report No. 188, KNMI De Bilt (with English summary).

Gilhousen, D.B. 2006. A Complete Explanation of Why Moored Buoy Winds are Less than Ship Winds. Mariners Weather Log, 50, 1, http://vos.noaa.gov/mwl.shtml

Hoffman, R.N. and S.M. Leidner, 2005. An introduction to the near-real-time QuikSCAT data. Weather and Forecasting 2005, 20, 476-493.

Howden S., D. Gilhousen, N. Guinasso, J. Walpert, M. Sturgeon and L. Bender, 2008. Hurricane Katrina winds measured by a buoy-mounted sonic anemometer. Journal of Atmospheric and Oceanic Technology, 25, 607-616.

Ingleby, N.B. 2009. Factors affecting ship and buoy data quality: a data assimilation perspective. Met Office, Met R&D Technical Report 529.

Keogh, S.J., B. Candy, Z. Jelenak and P. Chang, 2008. The impact of an improved QuikSCAT wind product on Met Office global forecasts and analyses. Met Office FRTR 524.

Keogh, S.J. and D. Offiler, 2005. Seawinds Revisited. Met Office FRTR 472.

Thomas B.R., E.C. Kent and V.R. Swail, 2005. Methods to homogenize wind speeds from ships and buoys. International Journal of Climatology, 25, 979-995

World Meteorological Organization (WMO), 2007. International List of Selected, Supplementary and Auxiliary Ships. WMO No. 47, Geneva, Switzerland.

Yelland, M.J., B.I. Moat, P.K. Taylor, R.W. Pascal, J. Hutchings, and V.C. Cornell, 1998: Wind Stress Measurements from the Open Ocean Corrected for Airflow Distortion by the Ship. J. Phys. Oceanogr., 28, 1511–1526.

9. Acknowledgements

Thanks go to Bruce Ingleby for help with processing ship and buoy winds. Thanks also go to Mary Forsythe for help performing the bias correction and to Dave Offiler for general scatterometer advice.